

Procedure Electromagnetic Testing Eddy Current Inspection Installed Heat Exchanger Tubing

Document 1: Qualification & Certification

Document 2: Inspection Procedures

Document 3: Report Procedures

Document 4: Recommendations

Document 5: Frequency & Calibration

Written Practice



Document 1 Procedure Established for
Qualification and Certification of
Eddy Current Tube Analysis Technicians

1. Scope

- 1.1 The effectiveness of NDT depends upon the capabilities of the personnel performing NDT. This procedure has been written to establish criteria for the qualification and certification of Eddy Current Tube Analysis Technicians, installed heat exchanger tubing.
- 1.2 The American Society for Nondestructive Testing, Inc. Recommended Practice No. SNT-TC-1A 2006 has been used as a guideline for the establishment of this written practice.
- 1.3 All ETT's will be qualified and certified in accordance with this Written Practice.

2 Definitions

- 2.1 Terms included in this document are defined as follows.
 - (1) Certification: written testimony of qualification.
 - (2) Qualification: demonstrated skill, demonstrated knowledge, documented training and documented experience required for personnel to perform ET at each level of Certification.
 - (3) Certifying Authority: The persons designated in this written practice to sign certifications on behalf of the certifying agency.
 - (4) Certifying Agency: Employer
 - (5) ETT: Eddy Current Tube Analysis Technician
 - (6) ET: Eddy Current
 - (7) NDT: Nondestructive Testing

3 Levels of Qualification

- 3.1 There are three levels of qualification for tube analysis technician.
 - (1) Level I ETT: A Level I ETT will be qualified to properly perform calibrations in accordance with Procedure Document 5.4. The Level I ETT will perform ET evaluations for acceptance or rejection in accordance with Procedure Document 4 and record test results. The Level I ETT will receive the necessary instruction or supervision of a certified Level III ETT individual or designee.
 - (2) Level II ETT: A Level II ETT will be qualified to set up and calibrate equipment and to interpret and evaluate test results in accordance with Procedure. The Level II ETT will be thoroughly familiar with the scope and limitations of the ET method as it relates to the internal inspection of installed heat exchanger tubing. The Level II ETT will exercise assigned responsibilities for on the job training of trainees and Level I ETT personnel. A Level II ETT will be responsible for

organizing and preparing the report of eddy current inspection in accordance with Procedure.

- (3) Level III ETT: A Level III ETT will be capable of establishing techniques and procedures; interpreting codes, standards, specifications, and procedures; and designating the particular techniques, and procedures to be used as it relates to the internal inspection of installed heat exchanger tubing using the ET method. The Level III ETT will be capable of interpreting and evaluating test results in terms of existing codes, standards and specifications. The Level III ETT shall have sufficient practical background in applicable materials, fabrication and product technology to establish techniques and to assist in establishing acceptance criteria when none are otherwise available. The Level III ETT will have a general familiarity with other NDT methods, as demonstrated by the Level III ETT Basic Examination. A Level III ETT will be capable of training and examining Level I ETT & II ETT personnel for certification in the ET method.

4 Education, Training and Experience Requirements for Initial Qualification.

- 4.1 Personnel being considered for initial ETT certification will complete the ETT organized training program. This is an 80 hour program covering the following:

History of ET	Tube Bundle Mapping
Frequency Selection	Probe Design
Principles of ET	Strip Charts
Working Vocabulary	Location Sheets
Test Equipment	Vessel Information
Defect Pattern Interpretation	Summary of Inspection
Common Defects & Possible Causes	Calibration Standard
ASNT SNT-TC-1A	ASME & ASTM Codes

- 4.2 In addition to completion of the ETT organized training program each person being considered for certification must meet the following experience levels for performing ET of installed heat exchanger tubing.

Level I ETT	3 Months
Level II ETT	9 Months
Level III ETT	4 Years & Successful completion of Level III ETT examination.

A valid ASNT Level III ET Certificate will also meet the requirements for certification to Level III ETT. Other Level III certifications will be reviewed on a case-by-case basis. The certifying authority must verify the certified

individual's experience level and insure the individual understands Procedure.

- 4.3 A valid ECUTEC Level II Certificate as an acceptable alternative to completing the organized training program. The certifying authority must verify the certified individual's experience level and insure the individual understands Procedure.

5 Examinations

5.1 Administration and Grading

- (1) The certifying authority will be responsible for the administration and grading of examinations for Level I ETT, II ETT and III ETT personnel.
- (2) For Level I ETT & II ETT personnel a composite grade will be determined by simple averaging of the results of the general, specific and practical examinations described below. For Level III ETT personnel a composite grade will be determined by simple averaging of the results of the basic, method and specific examinations described below.
- (3) For Level I ETT & II ETT personnel a passing composite grade of at least 80% is required a passing grade of at least 70% for the general and specific exams is required and a passing grade of 100% for the practical examination is required. For Level III ETT personnel a passing composite grade of at least 80% is required. A passing grade of at least 70% for the basic and method exams is required and a passing grade of 100% for the specific exam is required.

5.2 Vision Examination

- (1) The certified individual will with natural or corrected near-distance acuity in at least one eye be capable of reading a minimum of Jaeger Number 2 at a distance of not less than 12 inches on a standard Jaeger test chart. The certifying authority will administer this eye examination annually.

5.3 General Examination for Level I ETT & II ETT written and closed book.

- (1) The general examination will address the basic principles of ET covered in the ETT organized training program.
- (2) There will be 60 questions in this examination.

5.4 Specific Examination for Level I ETT & II ETT written and closed book.

- (1) The specific examination will address the equipment, operating procedures and ET techniques covered in the ETT organized training program.
 - (2) The specific examination will also cover accept and reject criteria used.
 - (3) There will be 40 questions in this examination.
- 5.5 Practical Examination for Level I ETT & II ETT
- (1) The person considered for certification shall demonstrate to the satisfaction of the examiner that they are familiar with and can operate the necessary test equipment.
 - (2) At least 20 selected specimens shall be tested and the results of the test shall be analyzed, recorded and reported by the person considered for certification.
- 5.6 Basic Examination for Level III ETT written and closed book
- (1) 15 questions relating to understanding the SNT-TC-1A 2006 edition.
 - (2) 20 questions relating to applicable materials, fabrication and product technology.
 - (3) 20 questions that are similar to published ASNT level II questions for other NDT methods.
- 5.7 Method Examination for Level III ETT written and closed book.
- (1) 30 questions similar to published ASNT questions relating to the fundamentals and principles of the ET method.
 - (2) 15 questions similar to published ASNT questions relating to application and establishment of techniques and procedures for ET.
 - (3) 20 questions relating to capability for interpreting codes, standards and specifications relating to ET.
- 5.8 Specific Examination for Level III ETT
- (1) Person considered for certification will be required to write a procedure, accept/reject criteria or a specification based on a scenario given him by the examiner.
 - (2) Person considered for certification will be given 1 week to complete this task and may use any references the examiner allows.
 - (3) This will be a pass or fail examination pass will equal 100% fail will equal 0%.
- 5.9 Reexamination
- (1) Those failing to attain the required grades will wait at least 30 days or receive suitable additional training as determined by the certifying authority before reexamination.

6 Certification

- 6.1 Certification of all levels of NDT personnel is the responsibility of the employer.
- 6.2 Certification will be based on the demonstrated ability and satisfactory qualification in accordance with qualification and certification procedures.
- 6.3 Personnel certification records will be maintained by the employer and will include the following.
 - (1) Name of certified individual
 - (2) Level of certification and NDT Method.
 - (3) Educational background and experience.
 - (4) Statement indicating satisfactory completion of training in accordance with qualification and certification procedures.
 - (5) Results of vision examination.
 - (6) Evidence of successful examination completion.
 - (7) ECUTEC Level II certification if applicable
 - (8) Composite Grades
 - (9) Dates of certification.
 - (10) Currently issued certification number.
 - (11) Signature of certifying authority.
- 6.4 The employer will issue a certificate to all certified individuals.
- 6.5 Recertification
 - (1) All Levels of certification will be recertified periodically in accordance with the following criteria:
 - (a) Evidence of continuing satisfactory performance as perceived by the certifying authority.
 - (b) Reexamination of NDT personnel as determined by the certifying authority.
 - (c) Recertification will be within 3 years for Level I & II ETT and within 5 years for Level III ETT.
 - (d) NDT personnel may be reexamined at any time at the discretion of the certifying agency.
 - (e) Any disruption of 6 months or more in service will require reexamination and recertification.

7 Termination

- 7.1 Certification is revoked when employment is terminated.

8 References

8.1 The below listed references are suggested study for successful completion of the Level III ETT examination. All references are available from ASNT.

- (1) NDT Handbook-Second Edition, Volume 4
- (2) NDT Hand book-Second Edition, Volume 10
- (3) NDT Handbook-First Edition
- (4) ASNT Level III Study Guide: Basic Revised
- (5) ASNT Level III Study Guide: Eddy Current Method
- (6) SNT-TC-1A 2006
- (7) Materials And Processes For NDT Technology
- (8) ASME Article 8
- (9) The ASTM Standards
- (10) Mathematical Formulas And References For NDT-Eddy Current

9 Certifying Authority

9.1 _____ has been designated as
Certifying Authority.

Procedure
Document 2 Inspection Procedure

- 2.1 Inspection Procedure**
- 2.2 Machine Data**
- 2.3 Standard Practice**

Procedure
Document 2.1 Inspection Procedure

- 2.1.1 The following inspection procedures shall be adhered to by all performing eddy current inspections. Any deviation from this procedure shall be noted and attached to the Eddy Current Tube Analysis Report for review by the report reviewer.
- 2.1.2 The test equipment should be set up in a way that is most advantageous to the analysts viewing. All cords, cables and probes should be connected. The test object should load the test probe coils. (Follow the equipment manufactures set up procedures) The test equipment should be turned on, nulled and placed in stand-by mode.
- 2.1.3 Job site and address should be checked for accuracy. Check machine information, serial number, model and chiller number. Review any past eddy current reports available.
- 2.1.4 Start record of inspection. Note the date, job location, equipment manufacturer, model number and serial number. Note the vessel being inspected, the end viewed from and tube/row information. The calibration and start time should be noted upon calibration completion. Note all defects by row and tube number. A description of the defect to include defect class will be noted. If more than one defect is found in a tube only the most serious defect will be noted. Tubes indicating missed expansion; missing land, not expanded or miss-formed land may be noted in the cover letter. Calibration will be checked once an hour or whenever improper function of the test equipment is suspected. The row and tube number will be noted at each calibration check. When a vessel is completed, calibration will be checked and the finish time noted. Repeat this procedure until all vessels are completed.
- 2.1.5 Draw the tube diagram. The diagram is the test end view of the bundle. It must be carefully drawn to represent the true tube layout. Tubes indicating defects must be marked with a symbol. A legend will be provided indicating each symbols meaning. An exception is when minor damage is noted in a majority of tubes. This should be noted in the Eddy Current Tube Analysis Report recommendation section.
- 2.1.6 The test equipment will be calibrated to the type of tube being tested. A machined calibration standard will be used for this procedure. The calibration standard will have artificial defects that relate to defects normally encountered. The test instrument is calibrated at the beginning of the test. Calibration is checked once an hour during operation. Calibration is performed if any of the following change probe, frequency, gain, phase, tube size or material. Calibration is checked if improper function is suspected. If improper function occurs calibrate and examine all tubes examined since the last known good calibration.
- 2.1.7 Retain calibration data for insertion in the Eddy Current Tube Analysis Report.
- 2.1.8 The analyst will inspect all tubes in the bundle unless otherwise noted on the job order sheet. The test probe is inserted the length of each tube in the bundle. The probe is withdrawn at the appropriate speed. The probes ideal fill factor is 85% or more. The minimum fill factor not less than 70%. Defects will be recorded on the tube bundle map as they are encountered. Defects will also be noted on the record of inspection as they are encountered.
- 2.1.9 After all tubes are inspected select tubes for data collection. If no measurable defects are noted a typical tube should be selected for data collection. If defects are noted collect data for one typical tube and data for at least one of each type of defect noted. The major defects should be referenced to the nearest support sheet. All data will be marked with the proper row and tube number. The data will be retained for inclusion in the Eddy Current Tube Analysis Report.

2.1.10 This inspection procedure will be repeated for each vessel inspected. Also note the distance between each support sheet. Retain all information collected for insertion in the Eddy Current Tube Analysis Report.

Procedure
Document 2.2 Machine Data

Withheld

Procedure Document 2.3 Standard Practice

2.3.1 Scope

Perform eddy current inspections on installed heat exchanger tubing to aid in assessing the likelihood of failure during service.

Eddy current testing is a nondestructive method of locating discontinuities in tubing made of materials that conduct electricity. Signals can be produced by discontinuities located either on the inner or outer surfaces of the tube, or by discontinuities totally contained within the tube wall. A test probe is inserted the length of the tube. The probe is energized with alternating currents at the appropriate frequencies. The electrical impedance of the probe is modified by the proximity of the tube, the tube dimensions, electrical conductivity, magnetic permeability and metallurgical or mechanical discontinuities in the tube. Each discontinuity produces an electromagnetic response unique to the anomaly detected. These responses are processed electronically and displayed on the test instrument for interpretation. The types of damage, which can be detected, are listed in Procedure Document 4.2.

This procedure is in compliance with ASTM E 690.

2.3.2 Written Practice

Procedure established for qualification and certification of eddy current tube analysis technicians is in compliance with the American Society for Nondestructive Testing (ASNT) document SNT-TC-1A 2006.

2.3.3 Supporting Documents

Procedure Document 2 Inspection Procedure, Document 3 Report Procedure, Document 4 Recommendations & Document 5 Frequency Selection and Calibration.

2.3.3 Results

Detect and report all relevant defects and discontinuities listed in Procedure Document 4.2. Defects will be reported by type, in amplitude or % & accept or reject.

2.3.4 Test Equipment

The test equipment shall be capable of energizing the probe coils at the appropriate frequencies, and shall be capable of sensing changes in electromagnetic response of the probe.

The system shall be capable of displaying data on an X, Y impedance plane.

The system shall be capable of recording the inspection data.

The inspection probe shall be designed for cross-axial mode and differential mode inspections.

The probes ideal fill factor is 85% or more. Probes shall be constructed and sealed to perform without failure or frequency drift for the entire inspection.

Inspection frequencies shall be determined based on tube alloy, wall thickness and tube configuration.

2.3.5 Calibration Standards

Calibration Standards used for system set up shall be of the same alloy, diameter, nominal wall thickness and configuration as the tubes being inspected. The tube shall be selected from a typical production run and exhibit low noise.

Calibration Standards used shall contain artificial discontinuities. These discontinuities shall be spaced to provide adequate signal resolution.

2.3.6 Personnel Qualifications

Personnel shall be certified in accordance with Written Practice in compliance with ASNT document SNT-TC-1A 2006.

2.3.7 Procedures

Prior to an inspection, the test instrument is set up and calibrated using a probe having the appropriate coil configuration and a calibration standard.

Calibration is checked once an hour during operation, at the end of the test period or when improper operation is suspected. If the test instrument is improperly calibrated, all tubes shall be reinspected since the last known good calibration.

Each tube shall be inspected unless otherwise specified in the purchase order.

The data will be observed and analyzed as the probe is inserted and/or withdrawn from each tube.

Defects are recorded on the tube bundle map.

The contracting firm will be briefed on the inspection results upon completion.

A written report will be completed and forwarded to the contracting firm.

2.3.8 Recommendations

Recommendation for corrective action shall be based on the progressive nature of the damage detected, history of the equipment tested and the limitations of the inspection method.

2.3.9 Report

The final report will include the following information.

Cover Page: Includes the test date, customer, customer address, equipment manufacturer, model number and serial number of the equipment tested.

Vessel Information: Includes vessel description, # of tubes, test end, tube description, tube composition and support information.

Recommendations: Recommendations for corrective action based on industry accepted accept/reject criteria.

Tube Maps: Color and symbol tube maps with defects marked by description and severity.

Data: Data for sample tubes showing defect severity.

Defect Summary: Includes charts comparing the number of defects detected by percent of bundle.

Calibration Data: Includes data for the calibration standard used and test instrument settings.

Record of inspection: Includes defects noted by row and tube number.

Procedures: Includes brief review of inspection procedures.

Procedure

Document 3 Report Procedure

- 3.1.1 The following report procedure shall be adhered to by all performing eddy current inspections. This procedure lists the minimum documentation requirements for the Eddy Current Tube Analysis Report.
- 3.1.2 The Eddy Current Tube Analysis Report will include, for each machine tested the following.
 - Cover
 - Table of Contents
 - Vessel Information
 - Recommendations
 - Tube Maps
 - Defect Summary
 - Test Equipment & Tube Data
 - Calibration Data
 - Record of Inspection
 - Procedures
 - Cover Letter if needed.
- 3.1.3 The cover letter is to inform the contractor of something unusual noted during the inspection. The cover letter is normally reserved for non-wear related discontinuities such as missed expansions and missing lands. Other discontinuities associated with the manufacturing process, which have been proven not to effect tube integrity, should be noted in the cover letter. The cover letter is not a forum to suggest any corrective action. Other unusual circumstances encountered during the inspection may be included. If no unusual circumstances exist the cover letter may be omitted.
- 3.1.4 The record of inspection will be included in the Eddy Current Tube Analysis Report.
- 3.1.5 The Vessel Information Sheet(s) will be included in the Eddy Current Tube Analysis Report.
- 3.1.6 Tube Maps for each bundle tested will be included in the Eddy Current Tube Analysis Report. The tube maps should indicate the end the bundle was tested from, the tube, row direction and the vessel name. The serial number of the machine tested should be placed in the upper right corner. All significant defects should be marked with a symbol unique to each type of defect, on the tube map. A legend indicating what each symbol means, number of tubes with that type of defect and percent of tubes with that type of defect should be included.
- 3.1.7 Data pages will include the vessel tested, the row and tube number and a description of any defects noted. Major defects should be referenced to the nearest support sheet. The IMP should depict the noted defect.

- 3.1.8 A calibration page will be included for each type and size of tube tested. The calibration page will include the following information. The machined defects in the calibration standard. The Frequency, Gain and Rotation of the test instrument. The horizontal and vertical volts per division settings of the test instrument.
- 3.1.9 The Procedure page will be included in the report. Including a brief description of the procedure use in performing the inspection.
- 3.1.10 Recommendation will be included for each type and size of defect noted.
- 3.1.11 Cover Page will include, the date the machine was tested, the location, manufacturer, serial number and analyst information.
- 3.1.12 The report will be reviewed by a Level III analyst and bound in the proper order described in the table of contents for distribution to the contractor.
- 3.1.13 The analysts will forward the reports to the contractor and retain a copy for future reference.

Procedure
Document 4 Recommendations

- 4.1 Defect Classification / Accept, Reject Criteria**
- 4.2 Types of Damage Detected**
- 4.3 Recommendations**
- 4.4 Re-Inspection Recommendations**
- 4.5 Locating Defects for Visual or Laboratory Inspection.**

Procedure
Document 4.1 Defect Classification
Class 1: Accept, Class 2: Accept Caution, Class 3: Reject

Internal Diameter

ID Pits, ID Defects & ID Flaws

Class 1:
1/5 div. or less deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:
Less than 2/5 div. deflection, vertical volts or phase shift indicative of 20%-40% base wall penetration

Class 3:
Greater than 2/5 div. deflection, vertical volts or phase shift indicative of > 40% base wall penetration.

Internal Diameter Metal Loss

Class 1:
1 div. or less deflection vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:
1-2 div. deflection, vertical volts or phase shift indicative of < 40% base wall penetration.

Class 3:
2 div. or more deflection vertical volts or phase shift indicative of > 40% base wall penetration.

Outside Diameter

OD Pits, OD Defects & OD Flaws

Class 1:
1 div. or less deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:
2 div. or less deflection, vertical volts or phase shift indicative of < 40% base wall penetration.

Class 3:
Greater than 2 div. deflection, vertical volts or phase shift indicative of > 40% base wall penetration.

OD Metal Loss

Class 1:
1 div. or less deflection vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:
1-2 div. deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 3:
Greater than 2 div. deflection, vertical volts or phase shift indicative of > 20% base wall penetration.

OD Metal Loss at Support Continuous Finned Tubes

Class 1:

1 div. or less deflection vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:

1-2 div. deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 3:

Greater than 2 div. deflection, vertical volts or phase shift indicative of > 20% base wall penetration.

Wear at Support Skip Finned Tubes

Class 1:

Deflection vertical volts indicative of < 10% wall penetration.
(.052" wall < .005" / .043" wall < .004")

Class 2:

Deflection vertical volts indicative of 10%-20% wall penetration.
(.052" wall .005"-.010" / .043" wall .004"-.008")

Class 3:

Deflection vertical volts indicative of greater than 20% wall penetration.
(.052" wall > .010" / .043" wall > .008")

Wear at Support Continuous Finned & Prime Surface Tubes

Class 1:

1 div. or less deflection vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:

1-2 div. deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 3:

Greater than 2 div. deflection, vertical volts or phase shift indicative of > 20% base wall penetration.

Longitudinal Defect & Longitudinal Flaws

Class 1:

1/5 div. or less deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 2:

1/5 div. – 2/5 div. deflection, vertical volts or phase shift indicative of < 20% base wall penetration.

Class 3:

Greater than 2/5 div. deflection, vertical volts or phase shift indicative of > 20% base wall penetration.

Bulges

Freeze Bulges Skip Finned Tubes / in Land Area

Class 1:

7.5% or less increase in diameter and phasing indicative of no significant tube wall thinning.

(.750" OD .052" wall .050" Bulge no thinning.)

Class 2:

7.5% -15% increases in diameter and phasing indicative of no significant tube wall thinning.

(.750" OD .052" wall .100" Bulge no thinning.)

Class 3:

Greater than 15% increase in diameter or phasing indicative of tube wall thinning.

Freeze Bulges Finned Area / Prime Surface Tubes

Class 3:

All freeze bulges in finned area or prime surface tubes.

Internal Expansion / in an inappropriate area.

Class 1:

Any expansion in an inappropriate area that does not indicate significant tube wall thinning.

Class 3:

Any expansion in an inappropriate area that does indicate significant tube wall thinning.

Dents / Constrictions

Dents

Class 1:

Any dent that the normal probe can pass that does not appear to be of significance.

Class 3:

Any dent that the normal probe cannot pass or appears to be significant.

(Significant dents would include those found under support sheets)

Constrictions

Class 1:

Any constriction that appears to be a part of the manufacturing process that a normal probe can pass and does not appear to be significant.

Class 3:

Any constriction that a normal probe cannot pass and appears to be significant.

(Significant constrictions would include constrictions found in a vessel were the water is on the tubes OD)

Atypical & Abnormal Indications

Atypical Indication

Class 1:
Atypical indications that do not threaten tube integrity.

Class 3:
Atypical indications that do threaten tube integrity.

Abnormal Indication

Class 1:
Abnormal indications that do not threaten tube integrity.

Class 3:
Abnormal indications that do threaten tube integrity.

Cracks, Possible Cracks, Possible Stress Cracks

Class 3:
Any crack, possible crack or possible stress cracks.

Plugged, Restricted

Class 3:
Any Plugged Tube

Class 1:
Any Restricted tube tested with a smaller diameter probe when no defects are found.

Class 2:
Any restricted tube not part of a wear pattern. Condition of tube is unknown.

Class 3:
Any restricted tube that is part of a wear pattern.

Procedure

Document 4.2 Types of Damage Detected

The test is designed to aid in assessing the likelihood of failure during service. It is not possible to specify an all inclusive reject level that would acknowledge all of the possible combinations of heat exchanger design, environmental factors, type and amount of use and acceptable level of operational shutdowns. The purpose of this test is to detect defects normally encountered in industrial air conditioning. Calibration standards are designed to simulate these types of defects. When other types of defects are suspected different calibration standards, test frequencies and even test probes may be required. Not all defects are of a sufficient size to disrupt current flow enough to be detectable. This is particularly true were irrelevant signals caused by metallurgical or mechanical variations generated during manufacturing occur. These irrelevant indications can mask lesser relevant discontinuities. Discontinuities adjacent to tube ends may not produce signals capable of detection due to end effect.

Detectable Damage

1. ID Pits, Defects & Flaws
2. OD Pits, Defects & Flaws
3. Internal Corrosion
4. External Corrosion
5. Internal Erosion
6. External Erosion
7. External Corrosion at Supports
8. Wear at Supports
9. Bulges
10. Dents
11. Constrictions
12. Expansions
13. Abnormal Indications
14. Atypical Indications
15. Deposits
16. Restrictions
17. Longitudinal Cracks
18. Radial Cracks
19. Longitudinal Defects

The defects listed have a high probability of detection in the following areas of tubing.

ID Pits, Defects & Flaws are normally detectable in the bay area of the tube.

OD Pits, Defects & Flaws are normally detectable in the bay area of the tube.

External and Internal erosion or corrosion in the bay areas, the lands, transition areas and under supports.

Wear at Supports due to vibration under Supports.

Bulges in the bay areas, the lands and transition areas.

Dents in the bay areas, the lands, transition areas and under supports.

Constrictions in the bay areas, the lands, transition areas and under supports.

Expansions in the bay areas, the lands and transition areas.

Abnormal Indications in the bay areas, the lands, transition areas and under supports.

Atypical Indications in the bay areas, the lands, transition areas and under supports.

Deposits in the bay areas, the lands, transition areas and under supports.

Restrictions in the bay areas, the lands, transition areas and under supports.

Longitudinal Cracks in the bay areas, the lands, transition areas and under supports.

Radial Cracks in the bay areas, the lands, transition areas and under supports.

Longitudinal Defects & Flaws are normally detectable in the bay area of the tube.

Procedure
Document 4.3 Recommendations

Withheld

Procedure
Document 4.4 Re-Inspection Recommendations

New Machine or No Defects	3 Years
Slight Damage Non Progressive	2 Years
Moderate Damage Non Progressive	2 Years
Excessive Damage or Progressive	1 Year or Less

Procedure Document 4.5
Locating Defects for Visual or Laboratory Analysis

- 4.5.1 This procedure was established to aid contractors in locating and preparing defects, found during an eddy current inspection, for visual or laboratory analysis.
- 4.5.2 Once the number of condemnable defects reaches a threshold that tube replacement is likely. Or when the type of defect warrants. We recommend pulling tubes for visual or laboratory analysis. The tubes to be removed are referenced in the recommendations section of the eddy current tube analysis report. Reference points are established to aid in defect location. Figure 1 illustrates a tube reference. Reference points for each bundle tested can be found in the eddy current tube analysis report, vessel information section.

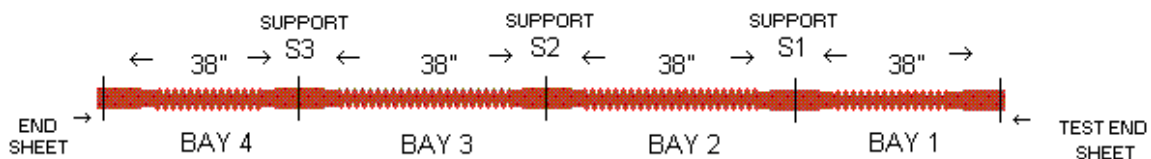


Figure 1.

- The test end is noted; this is the end of the vessel that the eddy current inspection was performed from. Test end information can be found in the eddy current tube analysis report, vessel information section. The area between the test end and the closest support sheet is referenced and labeled Bay 1. The closest support sheet to the test end is labeled Support 1. The area between Support 1 and the next closest support sheet is referenced and labeled Bay 2. The next closest support is labeled Support 2. This reference sequence continues the length of the tube to the end sheet opposite the test end.
- 4.5.3 The Eddy Current Tube Analysis Report includes sample data for tubes to be pulled for visual or laboratory analysis. Data information can be found in the eddy current tube analysis report, tube maps and data section. Vessel and tube information is noted on each data sheet. The strip chart (SC) information references defect location in inches from a support sheet or tube end. The impedance plane (IP) depicts the signal response of the test instrument monitor to the defect noted.
- 4.5.4 When a tube has been removed for visual or laboratory analysis the support or tube end reference point should be located. The tube should be marked at the point where the data sheet indicates that the defect is located. We suggest that a section of tubing including 6 inches of tubing on each side of the defect location be removed and labeled. The contractor should prepare the tube sample for further analysis in accordance with their procedures.

Procedure
Document 5 Frequency Selection & Calibration

- 5.1 Test Frequency Selection
- 5.2 Formulas
- 5.3 Test Frequency List
- 5.4 Calibration

Procedure
Document 5.1 Test Frequency Selection

CROSS AXIAL MODE Frequency 1

- 5.1.1 Choose a test frequency appropriate for the alloy and dimensions of the tubes being examined. Typically non-ferrous tubing 1 inch outside diameter or less. Preferred phase lag of 43 degrees. Inserting 2.3 in the frequency selection formula can accomplish this.
- 5.1.2 The optimum test frequency should be determined through experimentation with samples of the tubing being examined. The test probe diameter should be as large as possible, consistent with the need to pass through each tube freely.

DIFFERENTIAL MODE Frequency 2

- 5.1.3 Choose a test frequency appropriate for the alloy and dimensions of the tubes being examined. Typically non-ferrous tubing 1 inch outside diameter or less. Preferred phase lag of 72 degrees. Inserting 6.4 in the frequency selection formula can accomplish this.
- 5.1.4 The optimum test frequency should be determined through experimentation with samples of the tubing being examined. The test probe diameter should be as large as possible, consistent with the need to pass through each tube freely.

Procedure Document 5.2 Formulas

**Thickness to Standard Depth
of Penetration Ratio**

$$\frac{T}{S}$$

Standard Depth of Penetration

$$S = 2 \sqrt{\frac{P}{F \cdot \text{Ur}}}$$

UR = 1 for nonferrus

Phase Lag

$$B = \frac{T}{S} \cdot 57.3$$

Frequency Selection

$$F = 2.3 \cdot \frac{P}{T^2} \quad \text{XA Mode}$$

$$F = 6.4 \cdot \frac{P}{T^2} \quad \text{Diff Mode}$$

S = Standard Depth of Penetration in Inches.
P = Resistivity in Micro Ohms Centimeters
F = Frequency in Hertz
Ur = Relative Permeability
B = Phase Lag in Degrees
T = Thickness in Inches

TEST FREQUENCY LIST

5.3.1 Suggested test frequency list for some common chiller tubes. Optimum test frequency should be determined through experimentation with samples of the tubing being examined.

TUBE TYPE	OD	Cross-Axial F1	Differential F2
<u>COPPER</u>			
SF CU. .052/.035	.750"	3.5KHZ	9KHZ
CF CU. .052/.035	.750"	3.5KHZ	9KHZ
SF CU. .043/.028	.750"	5KHZ	14KHZ
CF CU. .043/.028	.750"	5KHZ	14KHZ
SFCU. IE. .055/.028	.750"	5KHZ	14KHZ
SF CU. IE .051/.025	.750"	5KHZ	14KHZ
PS CU. .028	.750"	5KHZ	14KHZ
SF CU. IE .053/.028	1"	5KHZ	14KHZ
CF CU. IE .053/.028	1"	5KHZ	14KHZ
PS CU. .035	1"	3.5KHZ	9KHZ
SF CU. .051/.035	.625"	3.5KHZ	9KHZ
CF CU. .051/.035	.625"	3.5KHZ	9KHZ
PS CU. .028	.625"	5KHZ	14KHZ
<u>CUNI. 90-10</u>			
SF CUNI. .052/.035	.750"	35KHZ	85KHZ
CF CUNI. .052/.035	.750"	35KHZ	85KHZ
PS CUNI. .028	.750"	50KHZ	132KHZ
PS CUNI. .035"	.750"	35KHZ	85KHZ
PS CUNI. .042"	.750"	20KHZ	59KHZ
<u>CUNI. 70-30</u>			
SF CUNI. .065/.049	.750"	20KHZ	86KHZ
CF CUNI. .065/.049	.750"	20KHZ	86KHZ
<u>TITANIUM</u>			
PS .028	.750"	100KHZ	200KHZ

CALIBRATION 1" OD OR LESS

CROSS-AXIAL MODE Frequency 1

- 5.4.1 Cross-Axial, Differential test probes shall be used when performing eddy current examination of non-ferrous tubing that has been installed in a heat exchanger.
- 5.4.2 Chose a probe with a diameter as large as possible, consistent with the need to pass freely through each tube.
- 5.4.3 Follow alloy identification procedure.
- 5.4.4 Choose a machined calibration standard of the same alloy, tube type and wall thickness as the tubes being tested.
- 5.4.5 Choose a test frequency consistent with a 43 degree ID to OD phase lag.
- 5.4.6 The machined calibration standard will have at least 6 artificial discontinuities. Standards 1" OD or less will contain, a .062" diameter through wall hole, a .093" diameter through wall hole, a .005 180 degree OD notch, a 360 degree OD notch, a simulated longitudinal through crack and a simulated radial through crack. All discontinuities shall be far enough apart to avoid interference between signals.
- 5.4.7 The test instrument gain and phasing will be set as follows: The .093 diameter through wall hole will display 4/5 of 1 division amplitude deflection, phased at approximately 220 degrees. Signal response of the 180 degree .005 OD notch will be phased 50-60 degrees clockwise from the .093 diameter through wall hole signal. Change in diameter will be phased horizontal from the null point. For skip fin tubes select a volts per division setting to produce a 3-6 division Land signal. An increase in diameter will move right from null. A decrease in diameter will move left from null. Increase in mass signals will move vertical up from the null point. A ring made of material similar to the tube supports should be used to simulate the signals obtained from the tube supports.
- 5.4.8 The amplitude and phasing response for each defect will be dependent on the disruption of current flow, consistent with the cross-axial probe design and test instrument gain setting.
- 5.4.9 This frequency divided by 2 will be used as a verification frequency if needed.

DIFFERENTIAL MODE Frequency 2

- 5.4.10 Choose a test frequency consistent with a 72 degree ID to OD phase lag.
- 5.4.11 The machined calibration standard will have 6 artificial discontinuities. A 20% and 40% ID anomaly, .042 and .062 diameter through wall holes and 40% and 20% OD anomalies. All discontinuities shall be far enough apart to avoid interference between signals.
- 5.4.12 Adjust the test instrument so that the phase angle of the signal produced by the 20% OD anomaly is between 50-120 degrees rotated clockwise from the signal produced by the .062 diameter through wall hole.
- 5.4.13 When pulling the probe the trace display of the 20% OD anomaly will move down and to the left first, followed by an upward motion to the right, followed by a downward motion returning to the point of origin.
- 5.4.14 The gain will be adjusted to produce a minimum 2 division peak-to-peak signal from the .062 diameter hole with the sensitivity set at .2 volts per division.
- 5.4.15 Adjust rotation so that signal response due to the 20% ID Anomaly is positioned along the horizontal axis.
- 5.4.16 This frequency divided by 2 should be used for verification frequency one.
- 5.4.17 This frequency divided by 4 should be used for verification frequency two.

Cross Axis Phase Analysis

- 5.5.1 Choose a test frequency consistent with a 90° to 120° IP display shift between a 20% ID anomaly and a 20% OD anomaly.
- 5.5.2 The machined calibration standard will have 6 artificial discontinuities. A 20% and 40% ID anomaly, .042 and .062 diameter through wall holes and 40% and 20% OD anomalies. All discontinuities shall be far enough apart to avoid interference between signals.
- 5.5.3 Adjust the test instrument so that the display response of the signal produced by the 20% ID anomaly is positioned at 180° from the point of origin.
- 5.5.4 When pulling the probe the trace display of the 20% ID anomaly will move right returning to the point of origin. The trace display of the 20% OD anomaly will move down returning to the point of origin.
- 5.5.5 The gain will be adjusted to produce a minimum 1-division signal from the .062 diameter hole with the sensitivity set at .2 volts per division. (X=Y)